Market-Based Conflict Resolution

for the LightSAR Mission

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Abstract

A Market-based system has been developed to assist in mission planning for a earth orbiting synthetic aperture radar (SAR) mission. The system enables participants to signal demands for spacecraft resources needed for data acquisitions by establishing a currency and "worth" for a particular data acquisition request. We compared a Serial Draft approach to two Market-based approaches; a Simple Market and a Priority Market. The market systems utilized a planning period which ended when the value of the time-ordered data acquisition plan did not increase by 10% of the value of the previous round. The Market-based approaches were superior to a Serial Draft approach and that a Priority Market had a 2% greater value than a Simple Market. conflict resolution

1.0 Introduction

In organizations, when demands for resources are greater than the supply available, conflicts naturally arise. The response to the conflicting demand for resources typically takes two distinct paths. There is always the response to increase the supply of resources to meet "requirements". We have assumed that resources are limited and that conflicts must be resolved by means other than simply asking for more resources. One response, generally found in large organizations, is to manage resource allocation decisions by committee, through negotiations. However, as more demands are placed on the system, the system becomes more and more congested, meeting times increase and many appeals to upper management occur. At this point, pleas are made to customers to reduce their demands or requests are made by managers requiring more information from customers concerning priorities and resource requirements. These are processed using algorithms to heuristically solve complex scheduling problems. A second approach to this problem is to create a "market-based" system in which participants "pay" for the use of resources and rationing is performed by allowing prices to move to signal the scarcity of resources. With this approach, participants signal demands and priority by their willingness to make trade-offs in their demands [1,2].

The question we address in this paper is the design of a market-based mechanism to assist the NASA/JPL LightSAR (lightweight synthetic aperture radar) mission in planning the use of spacecraft resources among participants. LightSAR is a NASA initiative to develop a low-cost Earth-imaging radar satellite system that will return valuable science data, commercialize radar imaging from space and demonstrate advanced technologies [3]. LightSAR definition studies developed business and teaming approaches, prepared market analyses, developed applications, defined technical approaches, and identified potential industry cost-sharing of follow-on development. LightSAR is also gathering experience from previous commercial space-based imaging radar efforts and experience from environmental operational monitoring programs [4],[5].

In general, resources can be machinery, buildings, people or expendables such as money, fuel, etc. For our purposes resources consist of the time available for an earth sensing synthetic aperture radar (SAR) on a spacecraft to be used for commercial and scientific data acquisitions. Other resources managed, as part of the SAR instrument operation, are the satellite power and the radar's observational modes (e.g., standby, calibration, image mode 1, image mode 2…)[3].

The traditional architecture used for mission planning, shown in Figure 1, consisted of a Mission Planning Board, the customers, the flight engineering team and the flight operations team [1]. The Mission Planning Board had the responsibility for allocating resources to customers and the flight engineering team and prioritizing the data acquisition requests and command sequences for the flight operations team.

One of the most time-consuming activities performed during mission operations is the conflict-resolution process for determining which customer's data acquisition requests take precedence over another. Conflicts for data acquisitions occur anytime there are multiple science and commercial objectives for a given instrument or multiple instruments with unique objectives, i.e., when the demands for spacecraft resources outstrip the available supply. For planetary and Earth-orbiting spacecraft, conflict resolution processes usually involve a "committee-driven" approach. This approach requires individual customers to submit requests for specific spacecraft resources to a "neutral party", namely the Sequence Integrators, Figure 1. These individuals integrate the requests into a single time-ordered plan of events that do not violate resource constraints. The Integrator's goal is to produce a "conflict-free" plan that maximizes the overall return for the mission while being "fair" to each customer. Fair in this context means that every attempt is made to integrate each customer's highest ranked requests into the listing.

The approach used by the Sequence Integrators is sometimes referred to as a "Serial Draft" or "Serial Dictator" method [6]. That is, the Integrators start with one customer and select their highest ranked request. The Integrator then moves to the next customer, selecting the customer's highest ranked request. This continues until the highest ranked request is incorporated from each customer. Once the cycle is completed, the Sequence Integrators select the second highest ranked request from the customer (science teams). However during this iteration, the order is reversed. The customer that had their highest ranked observation selected last, has their next highest ranked request selected first, and so on. If there are not enough resources for the given request, then the Integrator selects the next highest ranked request from that customer's prioritized list. This continues until either all of the requests are implemented or until the remaining resources , in our case, the available time, cannot accommodate additional data acquisition requests.

Once the Integrators develop a data acquisition plan, it is presented to the customers for evaluation. During this evaluation process, comments are submitted. Typically, those customers that have their requests incorporated into the data acquisition plan, evaluate the plan quite high. Those customers whose requests are not realized, evaluate the plan low. Since there is no formal mechanism to minimize the amount of appeals, most customers that "lose out", appeal the result.

Appeals involve presenting the merits of one customer's request over another to the Mission Planning Board or a senior project official. This appeal produces what is commonly referred to as a "Dead Weight Loss" [7]. That is, the losing Customer has lost all of their time and effort for the appeal and has nothing to show for it. The end result is that multiple meetings with multiple appeals and integrations of the plan are performed until the time for developing the data acquisition plan has expired.

The traditional architecture put the Mission Planning Board in the role of arbitrator of all of the customer's data acquisition requests. For missions which have both commercial and scientific objectives the role of the Mission Planning Board is further complicated. Many data acquisitions require that different imaging modes be used to achieve different spatial resolutions. Furthermore, the Mission Planning Board has been required to arbitrate customer needs with the needs of the engineering team responsible for the health, safety and maintenance of the spacecraft.

Moreover, a problem with the structure shown in Figure 1 is the lack of tradeoff information known to the Mission Planning Board. The Mission Planning Board can scrutinize requirements and can try to evaluate merits of different science requests against commercial requests, however, the Mission Planning Board lacks the information to determine the relative impact on commercial or scientific return based on denying a customer data acquisition request. In addition, once a change to requests has been tendered there are impacts on other requests that will have to be addressed. This cascade of requirement changes and interactions makes the job of the Mission Planning Board and the Sequence Integrators unenviable. How can the incentives and information of the customers be harnessed so that they are driven to supply the correct trade-off information so that the planners can make optimal use of resources?

To acquire trade-off information for making the optimal use of resources a prototype market-based planning system was developed for LightSAR.. A market-based system uses "rights" and "trades" to resolve conflicts instead of educated guesses by a third party. Each customer is allocated a "currency" for expressing the relative importance of one request over another. This currency, which we call " Priority Points", is budgeted to each customer who in turn assigns them to their data acquisitions to define the "worth" of the request. Customers are free to express the relative importance of their requests and make exchanges among themselves to enhance their positions. We point out that this market-based system resides on the Internet and allows customers located around the world to remotely interact to develop a resource timeline.

Market-based systems are not new, however their application to planetary exploration and Earth-orbiting programs are in their infancy. The Cassini Mission to Saturn used the first successful application of a market-based, computerized, multidimensional trading system from 1992 to 1996 for the development of science instruments [2]. Cassini distributed instrument mass, power, data rate, and funding to each science investigator and then set up the Cassini Resource Exchange (CRE) to electronically tender trades. The results were quite impressive. The total science payload cost grew by less than 1% while the mass decreased by 7%. Historically, most projects experience positive cost and mass growth during development and growths of over 200% can occur [2].

CRE has been successfully transferred to the commercial sector. The Automated Credit Exchange uses technology from the CRE to conduct quarterly auctions to trade emission credits among facilities in the Southern California Air Quality Management District's RECLAIM program. The Federal Communications Commission used the CRE system to test the auction system it now uses to allocate Personnel Communications Service Licenses. CRE technology has been applied to fixed income trading through State Street's BondConnect system. The main purposes of all these systems is to move the decision making process back to the individuals who have the most information and who have the most to gain, namely the users themselves.

The market-based system provides a uniform and equal representation of the plans to all customers. Moreover, the market-based system provides a uniform and consistent bidding and negotiation process to all customers. This is a critical feature in that scientists perceive that they do not have sufficient funds to compete with commercial customers. Also, commercial customers perceive a lack of sensitivity to market demands by the science community. Thus, for LightSAR to achieve its commercial and scientific objectives a system for resource allocation must be created that is based on an open process that is understood by the customers and the commercial partner.

2.0 Customers and Required Capabilities

LightSAR is designed to be a commercial mission. By commercial we mean that the system is designed to produce revenue and a profit for the commercial partner who is responsible for the system operation. As result of the primary goal of creating a commercial enterprise with LightSAR, the customer community is expected to use the system for private industrial applications, which require SAR data and government customers. However, in addition to the commercial objectives, NASA will provide LightSAR data to the scientific research community. Researchers began using spaceborne SAR data, for science research purposes, in 1978 when Seasat was launched [8]. Subsequent experience was gained with SIR-A, SIR-B, SIR-C, ERS 1/2, and JERS-1 and RadarSat. [9], [10].

Based on our experience with providing data to commercial applications projects and NASA researchers it is possible to characterize the planning needs of the commercial and scientific communities [11], [12. A comparison of the commercial and scientific community data needs shows that geographic coverage, temporal coverage, data acquisition timeliness, and data delivery timeliness can characterize their requirements for data. The Radarsat system approach reflects a similar set of experiences RadarSat [4]. Table 1 summarizes the spatial and temporal scales, which must be managed by the LightSAR market-based system. In addition, to these broad spatial and temporal categories, data collection modes specific to LightSAR which correspond to the radar capabilities, shown in Table 2, are needed for each of the spatial and temporal categories.

Table 2 summarizes the requirements for acquisition planning and shows that conflicts for resources are possible because of the need for simultaneous use of the radars to meet multiple customer requirements. For example it is expected that repeated high resolution imaging of urban areas along the Pacific rim will be needed at the same time as moderate resolution measurements using the interferometer mode. The Pacific rim contains large-population centers such as Los Angeles and Tokyo which commercial value-added processing companies view as primary targets for mapping highway systems, power distribution grids and pipelines in geographic information systems (GIS) applications. Similarly, the Pacific rim is tectonically active and the long-term mapping of this region with an interferometer capability is a major science goal [13]. A consequence of the repeating coverage, every 8-10 days, and variable resolution is that the market-based system must represent these capabilities in a data acquisition plan and manage changes to plans made by customers.

LightSAR will enable mapping of surface change, because its repeat-pass interferometry technique will enable continuous monitoring of Earth's dynamic topography to a height accuracy of a few millimeters. Moreover, LightSAR will have the ability to map large areas of the surface of the Earth, especially oceans, using a wide-swath mapping technique (ScanSAR) similar to that used in the Shuttle Radar Topography Mission (SRTM) [3]. To provide both high-resolution (i.e., the ability to map objects on small spatial scales) measurements for commercial interests (1-3m) and large-scale lower resolution geophysical measurements (25-100m), a dual frequency (L- and X-band) configuration was investigated as well as a single frequency (L-band) configuration with multiple polarizations to effectively map surface vegetation [14]. Thus, the market-based system must manage customer requests for data from different frequency radars with a diversity of polarizations.

To make LightSAR commercially viable and to obtain time series of data over multiple seasons, designs for missions with lifetimes of 3-5 years have been considered. A longer mission results in more measurements and more variations in the sampling frequency requirements needed to achieve the science objectives. The impact on the market-based system translates into the length of time represented in the "planning horizon." We define the "planning horizon" as the maximum length of time for which a customer can request data. For example, as shown in Table 1, researchers require data over months or years. It is impractical to set a planning horizon of only several orbits. At the same time the system becomes unwieldy if the planning horizon is five years and for each new request, and accepted bid, the entire plan must be recalculated. Therefore, a balance must be achieved between the overall system performance and the scope of requirements.

Superimposed on the data needs of commercial and science customers are the resource needs of the Flight Operations Team. They must manage planning events to meet both commercial and scientific objectives and the activities required to operate the satellite. Table 3 shows the time scales needed for planning by the Flight Operations Team. Mission management events are defined as those demands for instrument and spacecraft resources, which may preclude or reduce the resource availability for the commercial and science data acquisitions. Examples of mission management events are left/right roll maneuvers, calibration sequences, instrument mode change or payload reconfiguration events.

4.0 Conflict Resolution, Prototype Development and Demonstration

The current LightSAR design requires that the satellite have the capability to roll left or right to perform high-latitude mapping near the poles (up to 87.5° N and 87.5° S). This capability also is required in order to provide maximum coverage for NASA research science and responsiveness to commercial imaging customer's data needs. These capabilities must be captured in the market-based system to provide customers with fidelity in the planning process in order to resolve simultaneous requests for different pointing geometries (a "conflict"). The need to model the capabilities of the space system in the mission planning system was well understood by earlier SAR mission planning systems [15], [16]. The imaging angle diversity planned for a future RADARSAT mission was seen to require new planning system capabilities in order to determine the visibility of targets based on the imaging and surface geometry.

Earlier acquisition planning systems, such as SARPLAN addressed the planning needed to specify an image acquisition request for particular SAR viewing geometries [15]. This planning approach aids a customer in determining the optimal combination of viewing geometries for multiple satellites. The IRS-1C mission planning systems is used to plan and execute the complex operations of several sensors, which operate simultaneously [17]. The IRS-1C approach uses human-expert judgment to select the optimal plan for execution based on the input from customers. Another approach taken to mission planning divides the process into analysis and decision-making [18]. In this system, mission planning is approached from a thematic point of view in which images required to meet a user's thematic study are proposed, possible image acquisitions are matched to user preferences and the time and delays required to meet the image needs are determined. This technique begins to approach the LightSAR spatial and temporal approach to mission planning but unlike LightSAR, it does not resolve scheduling conflicts through a customer driven bidding process. The LightSAR market-based approach improves on these planning approaches by putting the planning process and the capability to prioritize the importance of a data acquisition request under the control of the customers. Moreover, a feedback and iteration mechanism allows for tailoring and alteration to form optimal requests under the constraint of competition for spacecraft resources. The major advancement this system is making, consists of integrating the generation of a timeline with the customer's priorities by eliminating the middleman Mission Planning Board. Therefore, the customer does not have to rely on a third party to determine whether their data request will be scheduled. Both the resources needed to acquire a time slot, the availability of an acquisition time and the priorities all customers place on the available time are known to everyone. Furthermore, the market-based system more fully automates the planning/sequence generation process. Conflict free plans can be automatically translated into spacecraft commands.

Development of the market-based system is based on implementing a functional prototype (testbed) and conducting experiments with a varied user base to evaluate, refine and demonstrate the system. Five development stages have been defined for the prototype; 1) Create an economy, 2) Allocate required resources, 3) Generate requests for resources, 4) Iterate the bidding/scheduling process, and 5) Conduct aftermarket trading. All five stages will function simultaneously when the system becomes operational. For prototype development purposes the system was built incrementally by adding capabilities presentation based on the requirements and customer feedback. Requirements, which guide the development of capabilities, are presented in Table 4.

The design of the system incorporates the requirements in a modular architecture. As shown in Figure 3 the customer interface and the bidding module are the major functional components. The system has a modular re-configurable architecture that enables rapid modification of parameters through the timeline configuration database which contains customer information, prioritization class descriptions, planning horizon constraints, engineering information and other predefined parameters. The customer interface is web-based and supports the formation of data acquisition requests, structuring of bids and the display of the total timeline of the data acquisition plan based on the current state of bidding. The customer interface module submits bid information to the pricing module. This module uses a maximization algorithm and a pricing algorithm to establish the prices customers are willing to pay for a data acquisition [19]. Results are returned to the customer interface and assessed in the context of whether the planning period is open for another round and convergence of the timeline and bid requests for allocations of time. If the planning period is closed, the timeline is sent to the sequence generation module where the period of data acquisitions and the operational modes requested are converted to spacecraft instructions. Typically, the planning period closes sufficiently in advance of the data acquisitions that time is available for aftermarket trading of data acquisitions and Priority Points by customers. The aftermarket was intentionally built in order to put further control of resources in the hands of the customers.

A representative customer group consisting of research scientists and college students conducted initial demonstrations of the system. This group brought a mix of ideas to the experiment about how satellite mission planning should be conducted. In general, both groups were tolerant of bugs in early versions of the software and provided valuable input on the efficacy of the design, e.g., whether convergence can be achieved in planning a data acquisition timeline. The students had no prior experience in satellite data acquisition planning and had no preconceived ideas about how the system should operate. In the first phase of testing only the students utilized the system. They performed the first set of functional tests and provided the initial feedback on system user interfaces and software reliability. Once the major bugs were resolved and successful trade studies were conducted, to narrow the range of possible bidding algorithms, a second phase of demonstrations were conducted. In the second phase of demonstrations, a group consisting of scientists familiar with the mission and science requirements evaluated the system along with the college students. The experienced scientists had certain expectations about the planning horizon, and the amount of effort they were willing to expend in setting up bids As the system matures and reliable performance is demonstrated the user group will be broadened to include representatives of commercial customers, scientists and operations personnel internal to the LightSAR project.

5.0. Market-Based Process Description

To implement a market-based system, an economy must first be created. To do so, a "currency" must be established and be distributed to each user based on some criteria. Users may be allocated budgets based on 1) their contributions to the project, 2) their past usage of the particular resources to be allocated, or 3) recommendations from an advisory board. The amount of currency, "Priority Points," available in the system is fixed and under the control of the project (i.e., the investors).

Next, each user defines the value of each of their requests as it relates to their scientific or commercial objectives. Table 5 shows an example of how a user might define the value of his data take requests. In this example, the Dual Polarimetry Customer ranks his desired data takes and then assigns them a value. Notice that in this example, the Customer has ranked data takes over Kuala Lumpur and Indonesia with a rank of two. If only this input was given to the Integrators, they would assume each location was equally important and would assign the data take easiest to incorporate into the time-ordered listing to Dual Polarimetry. However, Kuala Lumpur has a value of 45 while Indonesia had only 35. The two locations were not equal and the Dual Polarimetry Customer did have a preference.

Defining a value for each data take has another feature over a simple ranking, namely, bids provide tradeoff information and expresses the relative worth of each data take. As such, using Table 5, an Integrator would try to incorporate Vietnam (rank=1), followed by either Kuala Lumpur (rank=2) or Indonesia (rank=2). However, using value, the Dual Polarimetry Investigation would produce a greater value if Kuala Lumpur and Indonesia (45+35=80 points) could be incorporated into the timeline over just their number one ranked Vietnam (60 points) request. This shows that a simple ranking does not provide enough information to produce the highest value time-ordered listing.

a. Experiments

In order to test the ability of such a system to efficiently develop a timeline of data takes a set of controlled laboratory experiments were conducted. The use of experiments to evaluate comparative allocation systems has been a reliable source of scientific data [20], [21], [22]. The methodology of experimental economics is similar to the use of wind tunnels to test airfoil designs.

The main components of an experiment are 1) defining what is to be allocated, 2) setting individual incentives, and 3) defining the process by which resources are allocated. For this experiment, we defined fixed duration data acquisition periods as the resources to be allocated. There were four data acquisitions per orbit and four orbits per planning period. We used two planning periods such that subjects could carry-forward any unused Priority Points from period 1 to period 2.

Our subject pool was drawn from the undergraduate population at the California Institute of Technology. Subjects were assigned a customer role and responsibility for planning data acquisitions for one of the following: Dual Polarimetry, Quad Polarimetry, Interferometry, ScanSAR, Hi-Res Strip, or Spotlight. The subjects were compensated based how well they were able to get their data acquisitions into the time-ordered data acquisition plan. Subjects then bid for particular data acquisitions that would yield the highest values. A typical subject's bid is shown in Table 6.

Subjects submitted bids in rounds. Once submitted, successful bids could not be retracted. This ensured that bids were monotonic and that convergence to a solution with the greatest value was possible. Once bids were received from each subject, the round was closed and then solved for the solution that was conflict-free and that produced the greatest value (i.e., the largest feasible sum of Priority Points). Once solved, the next round began. Subjects could then see if their data take requests were incorporated into the listing or determine the number of Priority Points needed to "out bid" another user's successful data take request. The subjects had the choice to resubmit their bid with a larger number of points or choose some other data take. Once again, when all bids were received, the round was closed and then solved for the greatest value. The rounds continued until the value of the time-ordered listing did not increase by 10% of the value of the previous round.

The experiments were performed using rounds that lasted approximately 5 minutes apiece. This allowed the experimenters to run many experiments in a relatively short period of time to validate the experiment's design, find flaws in the operations of the experiment, and to vary initial conditions.

Experiments performed with the science community had much longer rounds. In that case, there were two rounds per day, one in the morning and one in the afternoon. A customer could log-on to the LightSAR simulation website, evaluate the time-ordered listing, submit their bids, and then log-off. The conditions for ending the planning period were the same as for the student experiments. That is, the planning period ended when the value of the time-ordered listing did not increase by 10% of the value of the previous round.

There are many ways to end these experiments (i.e., the planning period) and if not chosen carefully can produce undesirable results. For example, a specific time can be given for the close of a planning period. However, this method produces the undesirable incentive for all users to wait until the market is about to close before they submit bids. This keeps the bids low but rewards those users that are quick rather then promoting the highest value requests. To overcome the shortcomings, one might use a random closing time. Unfortunately, this approach could adversely effect the outcome if the market closed prematurely. For our experiments we used the "popcorn" method. In this case, as the market is "popping", bids are coming in and the overall value of the listing is increasing. The market closes when no bids are received over a predetermined period of time.

Another experimental result is that users do not know a priori how much to bid for a given data take request. Since successful bids cannot be retracted, there is an incentive not to overbid. As such, users bid the smallest amount needed to out bid the current request. This produces many small bids and an excessive number of rounds. To overcome this problem a Vickrey-type Auction was used.[1] In a Vickrey Auction, the winning bid "pays" the runner-up price. Thus, if Customer A submits a bid for 45 points and Customer B submits one for 60 points, Customer B "wins" the data take request and is debited 45 points from their account.

Vickrey Auctions provide the incentives for users to be forthright about their bids. If Customer A tried to underbid by submitting a bid that was lower then what they were willing to spend, Customer B could submit a bid much higher then Customer A's and only have to pay the Customer A's price. As such, users are given the incentive to make bids for the price they are willing to pay which in turn drives the system to a solution faster and reduces the required number of rounds.

[1] The Vickrey Auction is named after the Nobel Prize winning economist William Vickrey who first developed this auction and examined its properties [19].

b. Results

We compared a Serial Draft approach to two Market-based approaches (a Simple Market and a Priority Market). A Simple Market is one where users submit bids with Priority Points. In a Priority Market, users only had to specify the request's priority. For our experiments Priority 1 was high and Priority 5 was low. Each priority had a specific number or Priority Points associated with it. Figure 4 shows how a Simple Market and a Priority Market compare to a Serial Draft approach. Notice that both Market-based approaches were superior to a Serial Draft approach and that a Priority Market had a 2% greater value than a Simple Market.

In addition, the Priority Market used a Vickrey Auction method. Results show that users found specifying a request's priority more natural than specifying a bid "price". The Vickrey pricing strategy made the system more "forgiving" of bids that may have been too high and motivated customers to submit bids that honestly reflected their true desire for a particular request. Thus, the Priority Market was easier to use, encouraged the generation of accurate bids, and produced the desired conflict-free time-ordered listing in half the time of a Simple Market approach.

6.0 Conclusions and Plans

A market-based planning system was developed to improve the LightSAR mission planning process by putting the prioritization of data acquisition requests directly in the hands of customers. Planning for the allocation of resources is driven by: 1) commercial data acquisition events, 2) science data acquisition events and 3) mission management events. Experiments, which included research scientists as participants, revealed that there were few operational problems using a Priority Market approach. There were however, a number of concerns which were associated more with the experiment rather then weaknesses of the Market-based system. These concerns ranged from; who determines the initial allocation of points? The experiment was not realistic enough (i.e., not enough resources being allocated, not enough data takes, etc.), to how long is each planning period? These issues do not invalidate a Market-based system but reflect the rudimentary capability of the experimental system as compared to one that would be used for actual mission operations.

With the experiments completed and results that indicate that a Market-based system performs better than a simple ranking approach, we plan to conduct a third phase of demonstrations. In the third phase of demonstrations, a group of commercial and science customers, who represent the customer base expected to use the data after launch, will evaluate the system. This group is expected to be the most demanding in terms of requiring broad capabilities and robust performance. With the development of a prototype web-based planning tool, the system will include a customer interface that includes more capabilities for visualizing data acquisition requests on a map and in a timeline format. The system will rely on the current Market-based solver (with a Priority Market strategy) for developing a conflict-free time-ordered listing which can then be directly converted into spacecraft commands for operations.

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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Data Needs[1]	Commercial Customers	NASA Science Researchers
Access Coverage	Global	Global
Spatial Coverage for application	100 km x 100 km	Global, continent scale for long-term mapping, 100 km x 100 km for transient events
Temporal Coverage	One day to weeks	Months-years for large-scale mapping, days-to-weeks for transient events
Acquisition Planning Horizon	Weeks to 24 hr before acquisition time	6 months to 24 hr before acquisition
Data Delivery Timeliness	<24 hr to three weeks	Weeks-to-months for large-scale global mapping, <24 hr for transient events (e.g., volcano eruptions, floods),
Radar Payload Primary Need[1, 2]	X-band high resolution	L-band all modes

1. Not exclusive. Each customer community will make some use of the other radar payload. This is not expected to exceed more than about 20% of the total need.
2. Table 1 defines the radar capabilities for X-band and L-band, other frequencies are possible.

Table 1. Characterization of customers and their data needs.

Data Collection Mode:	HiresX	HiresL	Repeat-pass I/F	Quad-pol	Dual-pol	ScanSAR
Frequency	X-Band	L-Band	L-Band	L-Band	L-Band	L-Band
Resolution (m)	1	3 or 5	40	25	25	100
Swath (km)	10	10	90	30, 60	50	280
Imaging Angle	25 - 45°	25 - 45°	25 - 45°	20 - 40°	25 - 52°	20 - 52°
Polarizations	HH	HH or HH + VV[1]	HH or VV	HH, HV, VH, VV	HH, HV or VV, VH	HH, HV

1. H- horizontal polarization, V-vertical polarization, HH-transmit/receive horizontal polarization.

Table 2. LightSAR dual frequency design parameters.

Mission Management Event	Duration
Left/right roll maneuver	<10 min
Calibration sequence	<1 min
Instrument mode change	<1 min
Payload reconfiguration	<5 min
Orbit adjustment maneuver	minutes to days
Command sequence capacity	7 days
Command sequence update	< 24 hr
Minimum observation length	30 sec
Radar duty cycle	20 min/orbit
Observations	1-40/orbit
Orbit period	98 min
Science plan horizon	1 day- 5 years
Mission duration	5 years

Table 2. Mission management event requirements.

Required Capability	Rationale
1. Web-based, uniform user interface	Customers are geographically distributed, can access system from any browser equipped computer .
2. Maintains mission plan change history and role forward	Plan history must be rectified with subsequent requests to insure customer orders are completed.
3. Variable time scale plans	Planning time scale begins approximately six months before an acquisition and runs to within 24 hr of a data acquisition
4. Variable time resolution	Data acquisition period must be resolvable to 10 sec. to be on a scale commensurate with geographic scale of customer interests
5. Payload function selectability	Support customer's selection of different payload and payload operating modes.
6. Utilizes mission management events timescales	Mission management events (Table 3) require resources and impact customer's requests for data acquisitions.
7. Bidding, negotiation, trading system	Bidding period in consonance with data acquisition planning timescale. Open rules for bidders . Data resource bidding awarded as a function of bid magnitude and priority.
8. LightSAR market economy	Must create a currency to be used for bidding on mission resources.
9. Resource allocation	Customers specify mission resources to create data acquisition plans. For example, start time, duration, payload configuration (L-band, quad-pol, etc.)
10. Resource request generation	Customers submit requests, which include resource usage and priority. Priority implies a price to be deducted from the requestor's Priority Point budget.
11. Bid and iterate	Algorithm maximizes the number of points taken to create a tentative schedule. The schedule is posted for all to see and new requests are submitted. A new request must have a higher value than tentatively scheduled conflicting requests. Process stops when there are no changes in the schedule or the market time ends.
12. Aftermarket trading	Customers can buy and trade Priority Points, trade scheduled times. Real-time changes (e.g., volcano eruption monitoring) are priced at 2x the displaced data acquisition value. Changes in supply of the scheduling points remain under the control of the investors.

Table 3. Required capabilities for a market-based system.

Location	Orbit Number	Data Take Number	Rank	Value
Vietnam	1	1	1	60
Kuala Lumpur	1	3	2	45
Indonesia	1	4	2	35
Cambodia	2	3	3	10

Table 5. An example of Dual Polarimetry data acquisition requests.

Status	Location	Orbit Number	Data Take Number	Value	Bid (Priority Points)
New	Vietnam	1	1	60	25

Table 6. A typical bid showing its status and the number of Priority Points.

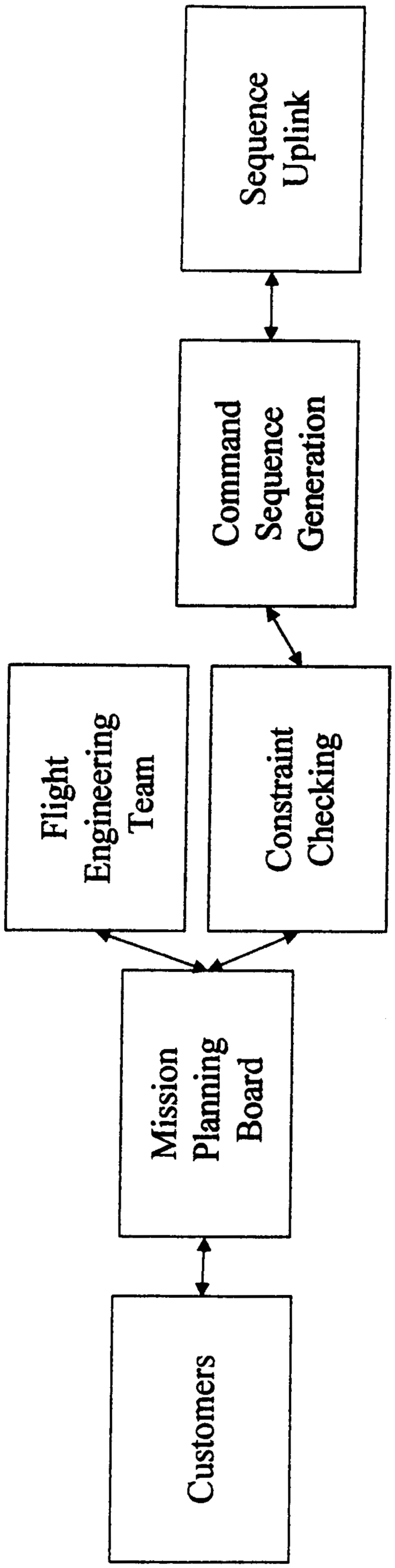

Figure 1. Traditional mission planning architecture

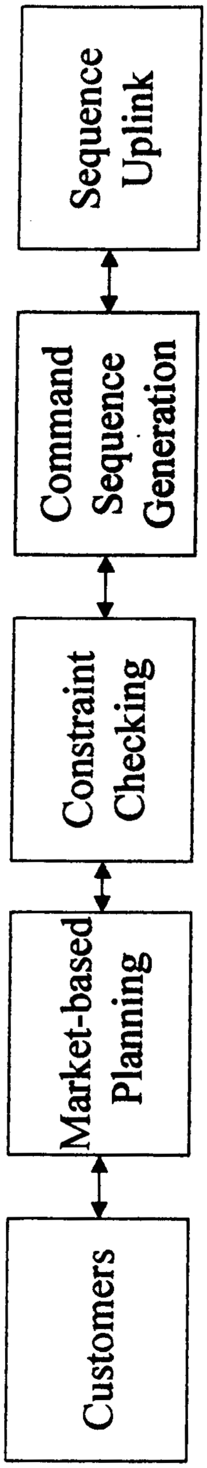

Figure 2. Market-based Mission Planning Architecture

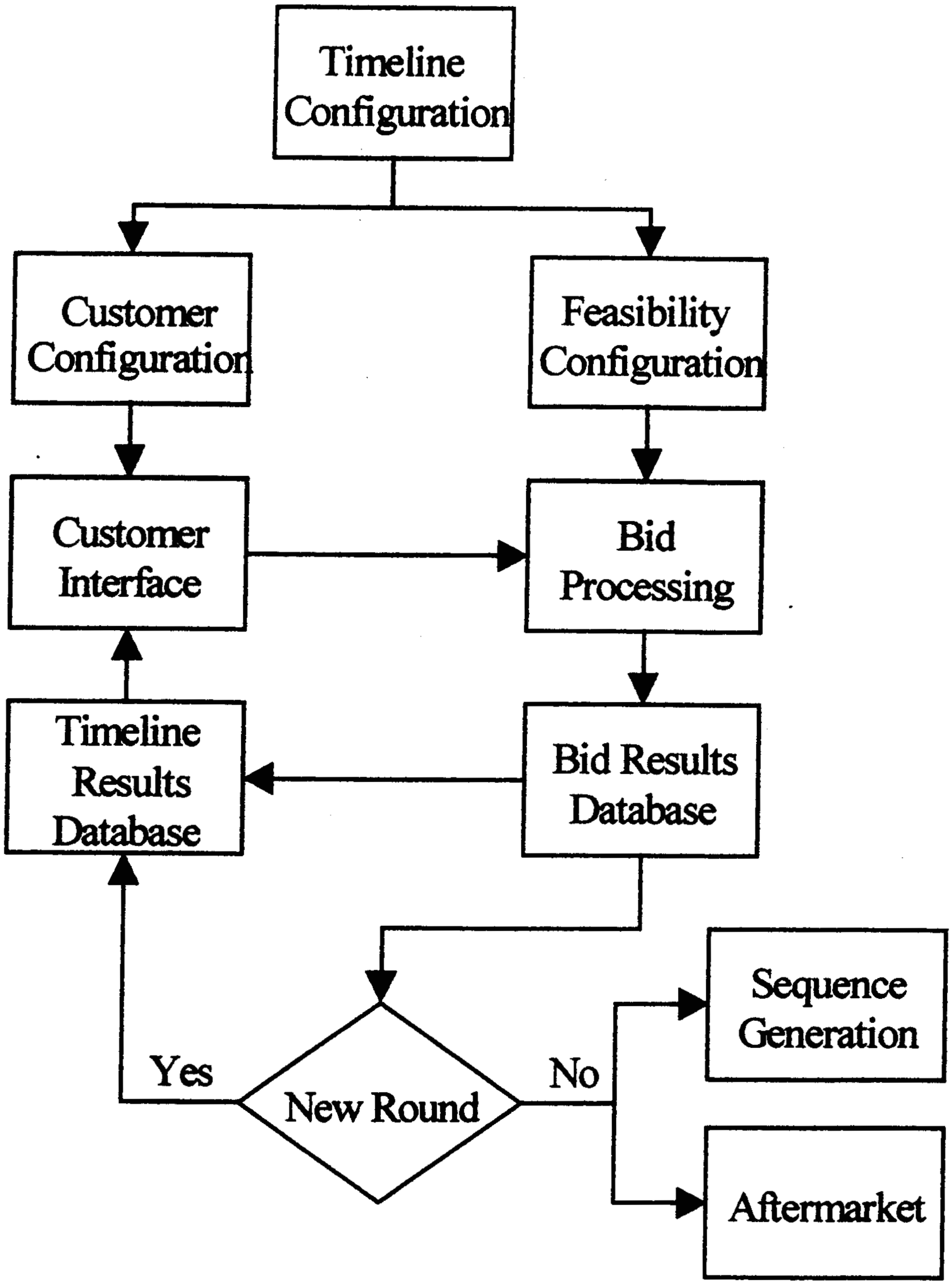

Figure 3. Market-based system software architecture.

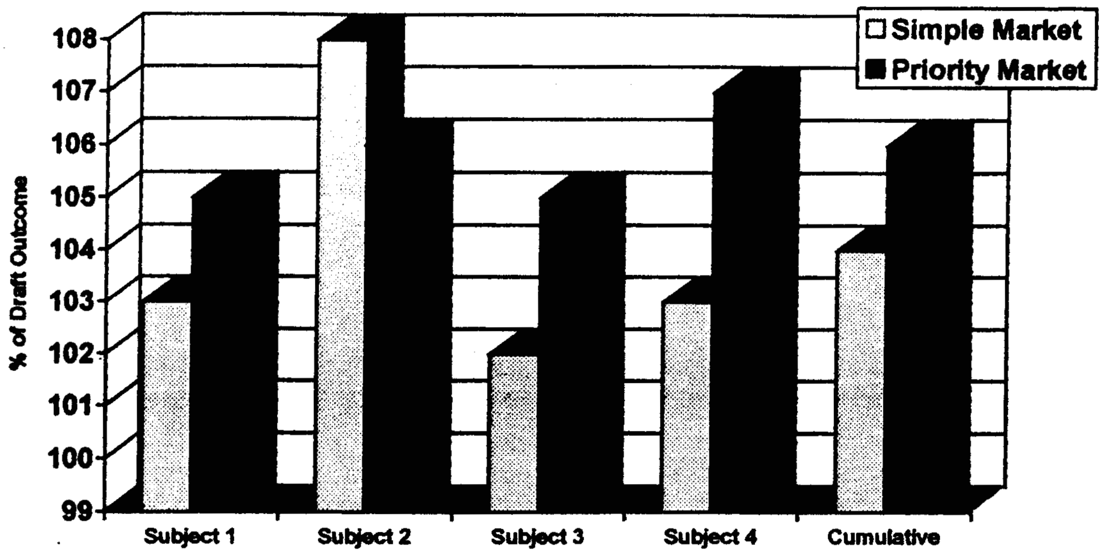

Figure 4. Percent value increase of a Simple and Priority Market over a Serial Draft approach.

Key phrases

synthetic aperture radar (SAR), mission planning, market-based planning, data acquisition